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25 June 1969

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To: Central Intelligence Agency
Washington, D. C.

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Proposal: To continue the program of research in image processing
STAT by amendment to Contract in the amount of STAT
of Central Intelligence Agency funds.

Starting Date and Period of Time Covered: Beginning on 1 July 1969
and continuing until 1 October 1969.

STAT Principal Investigator: , Research Engineer and
STAT Associate Director,

General Background: The has been conducting STAT
under funding from the Central Intelligence Agency (Contract No STAT
STAT a continuing program of research in the restoration of
degraded photographic images by means of computer processing. Fund-
STAT ing in response to Proposal covered a 3-month period end-
ing 1 July 1969. The present proposal calls for a continuation of the
effort from 1 July 1969, to 1 October 1969. The following is a brief de-
scription of the status of the several tasks which have received effort in
the course of this research program.

Task I: On-Line Computer Operation. The research program utilizes an IBM-1800 computer which is leased with the cost equally shared by the Central Intelligence Agency and the Advanced Research Projects Agency
STAT The sometimes finds it efficient to utilize time on the IBM-1800 when available, for work on other Laboratory contracts or grants. When this is done, the appropriate cost of that time is recharged to the contract or grant involved.

Substantial progress has been made in achieving flexible and efficient software for performing the image processing research. The utilization of the computer has been dramatically increased by the development of an unattended night operation in which the computer receives its instructions from cards rather than the keyboard. The instructions are still given in the language of image processing, and techniques have been developed such that the cards are easy to prepare.

The unattended card mode of operation has been supplemented by the addition of a 35 mm [redacted] STAT camera whose shutter and film advance mechanisms are computer controlled. This allows pictures to be made during all night runs.

A very recent development tremendously enhances the ability to make parametric studies in the unattended mode of operation. In a parametric study, there is usually a sequence of operations which is repeated many times with one or more important parameters incremented during each repetition. The new software allows the operator to advise the computer that he desires the computer to memorize a sequence of operations which he then enters. He also indicates the starting values and increments for each parameter and the number of times the sequence is to be run. In this way a very small number of cards of instructions, taking only minutes to prepare, is all that is required to handle calculations lasting many hours. Coupled with the [redacted] STAT camera, runs involving 40 hours of computation and producing 600 output pictures have already been made.

Within the last several months a new form of array indexing has been implemented in the software resulting in reduction in time by factors of 25 to 50% depending on the nature of the specific operation involved. Increased use of the computer sense and data switches has also been achieved. These switches are used to make routine decisions, as for example, is a gamma other than unity to be introduced into a displayed picture. There are now 13 such switches in use resulting in a substantial reduction in the time required for typewriter communication.

Task 2, Equipment Engineering: Under the present funding, effort has been directed toward improved display capability. As explained in Proposal [redacted] STAT 18 April 1968, the level of funding provided in response to this proposal did not permit full exploitation of the concepts of improved display systems which have evolved during the course of the research. Nevertheless the recirculating or refresh display system has been achieved. In this equipment, an image can be loaded into a small core memory which is an integral part of the display unit. This core memory is then scanned repetitively at TV type rates and displayed on a cathode-ray-tube for direct viewing. This provides a flicker-free presentation not requiring photographic recording. An exploratory unit has been constructed and is presently being operated.

Supplementary circuitry has been constructed for the refresh display which provides what is called inner-raster-scan. The inner-raster-scan reduces the distracting discreteness of the displayed images by spreading the flux from a single data point over the region between data points in a controlled way. The particular weighting of the flux distribution is programmable. It is presently being operated in a mode which is equivalent to providing two-dimensional linear interpolation between data points. Preliminary results show substantial improvements in the appearance of the images. The inner-raster-scan is presently operable in a slow scan photographic recording mode because the circuitry will not allow the high scan rates which would be required for the direct view mode of operation.

Testing of the refresh display has been completed and the repackaging of the system for use with the computer is nearing completion.

Other equipment developments are being funded by the Advanced Research Projects Agency. Although they are not being paid for by the Central Intelligence Agency, they will be used for the Central Intelligence research program at the [redacted] STAT These equipments include an image dissector film scanner and a microscope flying spot scanner. The image dissector now exists in breadboard form and the microscope flying spot scanner is now under construction. These all-electronic scanners offer the advantage of putting the film scanning operations under computer control so that the operator can position the scan and choose the step size and array size at will. During these operations the scanning will be at TV rates to provide direct viewing on a c.r.t. display. The scan speed would be reduced for actual data taking to maximize the signal-to-noise ratio.

Task 3: Basic Restoration Investigation. The basic theoretical and experimental studies of optimum restoration techniques have been continued. Exciting progress has been made in non-Fourier techniques of image processing. These explorations have included extensions of the non-negative algorithm previously described, the application of linear programming, and an algorithm involving Baye's theorem. Each of these techniques have the inherent ability to utilize a'priori constraints on the image restoration as for example, boundaries on the object of interest, and non-negative luminance or brightness values. Preliminary studies have produced results which appear, in some cases, to be considerably better than Fourier processing of the same images. All three techniques are at present, time consuming with respect to the Fourier techniques.

Defocus degradations have received considerable attention. Laboratory photographs intentionally defocussed have been scanned and successfully restored. These first experiments have involved large amounts of defocus, i. e., low resolution photography where the film granularity situation is favorable. Experimental studies of defocus point spread functions for a [redacted] STAT camera have been made and it has been found that results are not in agreement with general defocus theory reported in the open literature. Explanations of this discrepancy have been postulated and are now being tested. Since the effect of this discrepancy would be greatest for small amounts of defocus and with high resolution, it is important to resolve this discrepancy prior to attempting image restoration on high resolution photography.

Image motion studies are presently underway. Restorations have been successfully performed on low resolution photography. High resolution restoration experiments will be made in the near future.

A technique known as "sanding" has been developed. This technique is based on the realization that when an image is degraded, the spatial derivatives of the image are reduced. A high value for a spatial derivative in a degraded image is probably due to film granularity or film defects such as dust, scratches, etc. The sanding operation explores the spatial deritives and alters data values to restrain the derivatives to any specified limit. Further effort is required to determine the capabilities and limitations of this technique.

Task 4: Dual Gamma Studies. The dual gamma studies have been in progress for several months. The initial effort was directed toward the development of a mathematical model of the process. The first model explains the adjacency effect on the basis of a granular visualization in which (a) there is a limited amount of developer present, (b) the number of grains developed in an increment of time is proportional to the quantity of developer available at that point, and (c) the developer has some limited amount of lateral mobility so that small area shortages in developer are resupplied from adjacent developer whereas large area shortages cannot be so resupplied.

This first simple mathematical model has been programmed on the computer in such a way that "latent images" can be subjected to this model of chemical processing. To date variable width bar images and a picture of the capital building have been processed in this way. The adjacency effect is evident in the bar imagery.

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Scope of Work: It is proposed that the program of research currently in progress under Contract [redacted] be continued for the 3-month period of July through September 1969. During this time period the effort will be directed to the several tasks as follows:

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Task 1: On-Line Computer Operations. The software which has been developed over the past years is performing well. It is not anticipated that there will be any dramatic changes undertaken during this funding period. Continuing support will be required to add new transfer functions and other operations as the needs develop in the course of the basic restoration investigations. It seems likely that a substantial portion of the programming effort may be directed toward operations required to perform smoothing of edge discontinuities and elimination of unwanted background noise. Recent restoration experiments have tended to indicate the importance of the development of such techniques.

Task 2: Equipment Engineering. It should be emphasized that the equipment engineering task has had the goal of supplying input-output systems adequate to the performance of the processing research on an efficient basis. When the image processing research was initiated there were no suitable scanner and display systems commercially available. This is substantially true today. The culmination of this work is the refresh display system presently being repackaged for use with the computer. The only addition to this display which is presently contemplated is a light pen capability for communicating complicated addresses to the computer, as for example, outlining an object of interest in an image for the purpose of invoking background smoothing operations. If undertaken, the light pen will be funded by the Advanced Research Projects Agency and is not a part of the work to be funded in the present proposal.

The equipment engineering effort to be supported by funds responsive to this proposal will be limited to a continuation of the repackaging effort on the refresh display system. It seems highly probable that this task can be completed during the 3-month period covered by this proposal.

Task 3: Basic Restoration Investigations. A limited effort will be continued on the non-Fourier processing techniques described in previous proposals. It should be emphasized that these techniques are not an equivalent to Fourier processing. Therefore, the goal is not an alternate technique for achieving the same results. The goal is better processing than can be achieved with Fourier processing by virtue of a more realistic treatment of film granularity and better utilization of a priori knowledge.

Numerical definition of the extent to which image processing can be accomplished as a function of resolution and film granularity will receive major attention during the funding period. Such definition will be undertaken for both defocus and image motion degradation.

Image processing experiments will be undertaken on photographic images degraded by image motion. The resolution associated with the imagery will be increased incrementally starting with approximately 20 lines per millimeter and working towards a goal of 100 lines per millimeter. It is not possible to predict the resolution range which will be achieved during this 3-month period because this will depend entirely on how much time is required to achieve successful results at each of the lower resolutions.

Task 4: Dual Gamma Studies. Examples of real dual gamma processed films and their conventional processed equivalents will be studied. The comparison of their Fourier transforms should indicate the extent to which the dual gamma processing has altered the imagery. An attempt will be made to computer process the conventional imagery using the dual gamma mathematical model to achieve results comparable to the actual dual gamma imagery. This will involve manipulating the several constants in the mathematical model in order to match the example of the real dual gamma processing.

Since the adjacency effects of dual gamma are spatially non-linear and heavily dependent on the local density gradients in the imagery, it would be expected that the effect would be most pronounced with sharp imagery and much less pronounced with badly degraded imagery. As an image enhancement technique it has the undesirable quality of failing under the condition where it is most needed. The mathematical model of dual gamma processing will be used to explore this premise, and will also be used to determine the extent to which the linear Fourier type image restoration can be employed as a function of the degree of adjacency present in the degraded imagery.

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Approved For Release 2003/08/05 : CIA-RDP78B05171A000300030016-7